WIND DESIGN GUIDE

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BBSC 433 – ARCHITECTURAL AERODYNAMICS

READING ASSIGNMENT 1 – URBAN DESIGN

CONTENTS

1.0 Introduction

All buildings affect the wind. However the effect of the building on the wind environment varies from site to site, depending on many factors such as wind speed, wind direction, height, shape, the neighbouring urban environment and so on. Sometimes a building will create a better urban wind environment and sometimes it may worsen it.

The magnitude of the effect a building may have on the wind is measured at ground or pedestrian level as this is where all activities occur. As explained further in later sections, it is a requirement of Auckland and Wellington District Councils that all large buildings are wind tunnel tested to ensure that designers are doing all they can to minimise the effect their building may have on the urban wind environment in the area.

Building consents will not be issued unless it can be shown that all design options have been considered and the best has been chosen so that wind environments are still safe and comfortable.

The purpose of this guide is to provide designers with ways to design well in urban areas with respect to wind. Previous wind design guides have had a particularly negative outlook – that is to say that effects have been outlined, but little was included on how to design well. This guide will provide this information and will be useful for designers as they will be able to design good buildings that are conducive to safe and comfortable urban wind environments.

The guide will provide information on the different effects buildings can have on the wind. Designers and architects will have a clear idea on how wind acts when it comes into contact with the urban environment and the effects it will subsequently have at pedestrian level.

Following this, information on how a range of different building forms interact with the wind is described, as well as information on detailing of particular design features, and remedial options that help to improve wind conditions at ground level.

2.0 Why Design for the Wind?

2.1 The Windy Wellington Environment

Wellington is the windiest city in New Zealand, and possibly one of the windiest in the world. It is well known for its strong and extremely cold southerlies; however northerlies are the most common winds, blowing up 38% of the time.

In an average year, Wellington:

- Experiences 18m/s gusts approximately 150-170 days compared to 70 days in Paraparaumu or 50 in Auckland
- Has a mean annual wind speed of 22km/h
- Averages 173 days a year with wind gusts greater than 60km/h

It is fairly obvious that Wellington is extremely windy, and is known for this. Due to its location next to the Cook Strait, Wellington is located in what is referred to as a River of Wind – virtually a wind corridor between the South and North Island.

The wind is funnelled through the gap, and is exasperated through the harbour, waterfront location of the Central Business District (CBD) and local hills and valleys creating high wind speeds.

The urban environment around Wellington city has a mix of low and high buildings. In areas where there are a large number of 2 to 4 storey buildings and relatively narrow streets winds speeds are on average the lowest. However where there are buildings with heights up to the height limit there are generally areas of increased speeds. The waterfront location of the CBD combined with the high number of very tall buildings and open spaces such as parks combine to produce areas of extreme wind speeds.

2.2 Comfort and Safety

Pedestrian Comfort is the most important factor to be taken into consideration when designing buildings and urban form. The design of a building and how it interacts with the wind directly effects the pedestrian ground level wind environment. Adverse changes in pedestrian level wind speeds and gusts can affect a wide range of activities including walking, shopping, dining, playing and so on. While generally wind creates uncomfortable environments, it can at times create dangerous environments. Pedestrian safety and comfort must always come first. Wind affects everybody in two ways – mechanically through the force it applies on the body and thermally through wind chill. When considering buildings and wind, the mechanical effect of wind is the only effect considered. It is at the higher wind speeds as shown below in the Beaufort scale that the force of the wind is felt the most and when safety becomes a problem. The following tables are general summaries of how wind affects people, and different activities. They are based on the Beaufort scale and are wind speeds measured at 10m above ground. It should be noted that wind speeds over Beaufort 8 (B8) or 17m/s are dangerous.

Table 1 – Beaufort Scale.			
Beaufort Scale	**Description**	**Mean wind speed range (m/s) @ 10m**	**Effects**
B0	Calm	0 – 0.2	
B1	Light Air	0.3 – 1.5	No noticeable wind
B2	Light Breeze	1.6 – 3.3	Wind felt on face
B3	Gentle Breeze	3.4 – 5.4	Wind extends light flag
B4	Moderate Breeze	5.5 – 7.9	Raises dust and loose paper. Hair disarranged and clothing flaps
B5	Fresh Breeze	8.0 – 10.7	Limit of agreeable wind on land
B6	Strong Breeze	10.8 – 13.8	Umbrellas used with difficulty. Force of the wind felt on the body. Wind noisy and frequent blinking
B7	Near Gale	13.9 – 17.1	Inconvenience felt when walking, difficult to walk steady. Hair blown straight.
B8	Gale	17.2 – 20.7	Generally impedes pedestrians, walking difficult to control. Huge difficulty with balance in gusts.
B9	Strong Gale	20.8 – 24.4	People blown over by gusts. Impossible to face wind, ear ache, headache, breathing difficulty. Some structural damage occurs, falling of roof tiles, tree branches etc. VERY hazardous for pedestrians.
B10	Storm	24.5<	Seldom experienced inland. Trees uprooted, considerable structural damage occurs
N.B. – Wind speeds measured at 10m above ground are reduced to about 75% at head height.			

<table>
<tr><th colspan="7">Table 2 – Comfort and Safety Criteria</th></tr>
<tr><th colspan="2">Activity</th><th>Areas Applicable</th><th>Perceptible</th><th>Tolerable</th><th>Unpleasant</th><th>Dangerous</th></tr>
<tr><td colspan="2">Walking fast</td><td>Pavements</td><td>B5</td><td>B6</td><td>B7</td><td>B8</td></tr>
<tr><td colspan="2">Strolling</td><td>Parks, entrances</td><td>B4</td><td>B5</td><td>B6</td><td>B8</td></tr>
<tr><td rowspan="2">Standing, sitting:</td><td>Short time</td><td>Parks, plazas</td><td>B3</td><td>B4</td><td>B5</td><td>B8</td></tr>
<tr><td>Long time</td><td>Street cafes, theatres</td><td>B2</td><td>B3</td><td>B4</td><td>B8</td></tr>
<tr><td colspan="4">Acceptable if speed occurs less than;:</td><td>Once a week</td><td>Once a month</td><td>Once a year</td></tr>
</table>

2.3 The District Plan

The Wellington City Council has developed a set of performance criteria for new buildings in the central area. It is this set of criteria that has been included in the District Plan.

Section 13.1.2.11.1 requires that new buildings or structures above 4 storeys in height shall be designed to comply with the following standards

Table 3 – Wellington City Council District Plan Performance Criteria for the Design of New Buildings above 4 storeys in height		
Existing Wind Speeds	**Wind Speeds Resulting from Development Proposal**	**Requirements on Developer**
	If exceeding 10m/s in any public space	Reduce to 10m/s in the public space
Up to 15m/s	If exceeding 15m/s	1 – Reduce to 15m/s 2 – Although other directional speeds may be increased towards 15m/s, overall impact is to be no more than existing
15 – 8m/s	If exceeding 15m/s	Reduce to max 15m/s
Above 18m/s	If more than 18m/s	Reduce to max 18ms/s

Section 13.1.2.11.2 requires that to show a proposed development complies with these standards, a wind report must be supplied which includes the results of a wind tunnel test which has examined the effects of the proposed buildings upon areas open to the public, i.e. parks, roads, pathways, malls, entrances etc.

It also states that the wind rules are designed to encourage a safe and pleasant environment by decreasing the worst effects of wind. The standards work to ensure that no development make the environment around buildings dangerous or makes the existing wind environment significantly worse.

The generally accepted effects of winds are as follows;

10m/s – the limit of comfort when sitting or standing for long periods in an open space

15m/s – the limit of acceptability for comfort while walking

18m/s – the threshold of danger level

23m/s – completely unacceptable for walking

3.0 The Basics of Wind

The wind is everywhere. You cannot stop it. However through good design you may minimise the impact it has on the pedestrian environment. The mains ways to do this are through deflection, shelter, diffusion and so on. These will be discussed in later sections. This section will give an overview of some of the main keywords, technical formulae and basic aerodynamic principles that are important in designing for the wind.

3.1 Keywords for Building Aerodynamics

Some important keywords are;

Porosity – How well the wind is able to pass through a surface.

Prevailing wind direction – The most common wind direction experienced at the particular location

Surface Roughness – Wind will not travel as smoothly through the urban environment compared to the rural environment because it has a rougher surface to travel across or through.

Turbulence – Instability in the wind causing gusty air currents

Viscosity – How well the wind is able to flow

Windward Face – The building face that comes into contact with the wind first

3.2 Wind Comfort and Danger

Wind comfort criteria usually consist of an equation which includes a discomfort threshold and probability of exceeding that threshold.

Bottema developed the following equation for wind comfort;

$$V_e = V + k.o_V > U_{THR}$$

V_e = equivalent wind speed

V = mean wind speed

k = peak factor

o_v = standard deviation of the wind speed

U_{THR} = threshold value at pedestrian height

Bottema further developed his equation to the following;

$$V_e = V + o_v > 6m/s$$

Here $k = 1$ and $U_{THR} = 6$ m/s, the threshold for walking comfortably.

Discomfort probability is defined as a percentage of hours a year in which the threshold is exceeded. Generally it is accepted that $P_{max} = 15\%$ (15% of the year it is acceptable to exceed the comfort threshold).

Wind Danger differs from wind comfort in that it can be directly related to wind effects.

The general formulae here are given as;

$$V + 3\sigma_v > 15m/s$$

$$V + 3\sigma_v > 20m/s$$

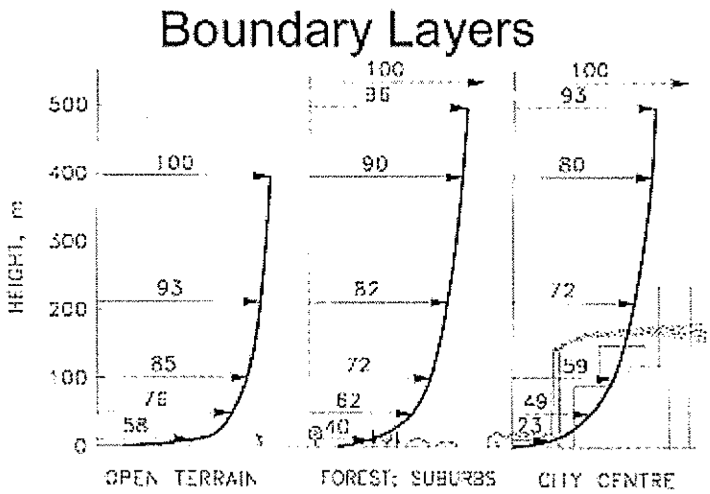
Where $P_{max} = 0.1\%$ or 1 hour per year.

These thresholds are related to the control of walking, the first equation is considered to be for elderly and the second for the average person.

3.3 The Boundary Layer and Power Law

The wind power law is a formula that is a relationship between wind speeds at one height and wind speeds at another.

It is a simplified version of the boundary layer principle which basically says that wind speeds increase as height above ground increases. The boundary layer diagram represents how wind speed is also affected by different types of terrain. The vertical scale is the height above ground level; the horizontal scale is the percent of uninterrupted wind. As the surface roughness and viscosity changes, more turbulence is created, so the wind speed is affected. The wind speed is not the same at similar heights across the different terrains.



The boundary layer and power law principles are useful in determining wind speeds (and wind loads) because due to the urban environment it is hard to measure average wind speeds in a heavily built up area such as a CBD.

The power law is given as;

$$V_z/V_{ref} = (H_z/H_{ref})^a$$

V_z = Wind Speed at height H_z (m/s)

V_{ref} = Reference Wind Speed at Reference Height H_{ref} (m/s)

H_z = Height (m)

H_{ref} = Reference Height

a = Power Law Exponent – constant depending on terrain

For open terrain a = 0.143, suburbs a = 0.25 and in CBD terrain a = 0.35 – 0.45

Using the Power Law equation it is easy to estimate the wind speed at a certain height once the equation is rearranged. Generally H_{ref} is taken in open terrain at a height of around 10m and these wind speed measurements are usually taken at an airport.

In Wellington the following is generally considered to be true;

V_{10} @ the Airport = V_{150} @ CBD

So the wind speed at 10m above ground in open terrain at the airport it generally considered to be the same wind speed at 150m above ground in the CBD. While the Power Law equation does not give this exact outcome, it has been done so many times in wind tunnel tests and enough measurements have been taken that they are close enough in practice to be the same.

So it is possible to estimate wind speeds around urban areas by looking at frequencies of wind speeds at the airport and relating them to wind speeds of similar frequencies around urban areas in conjunction with the power law.

3.4 Mean Speeds and Gust Speeds

Mean wind speeds and gust speeds are slightly different. A mean wind speed is generally the average wind speed over a period of 10 minutes, whereas the gust speed is generally considered to be mean speeds of 3 second gusts.

Mean speeds and gusts speeds are related in the following equation;

$$V_{zg} = V_z + 3.5 * o_v$$

V_{zg} = Gust Speed at height z

V_z = Mean Speed at height z

o_v = standard deviation of the wind speed

3.5 Porosity and Wind Shelter

Gandemer's wind shelter formula is an estimate of the amount of shelter provided behind a windbreak.

The shelter factor formula is given as;

$$\text{Shelter Factor} = (V_{ref} + T_{ref})/(V_z + T_z)$$

V_{ref} = Wind Speed at Reference Height

V_z = Wind Speed at Height z

T_{ref} = The Turbulence at a given Reference Height

T_z = Turbulence at Height z

Gandemer's general wind shelter formula is given as;

Shelter behind wind break = Constant.f(Length).f(Height).f(Porosity).f(Angle).f(Terrain)

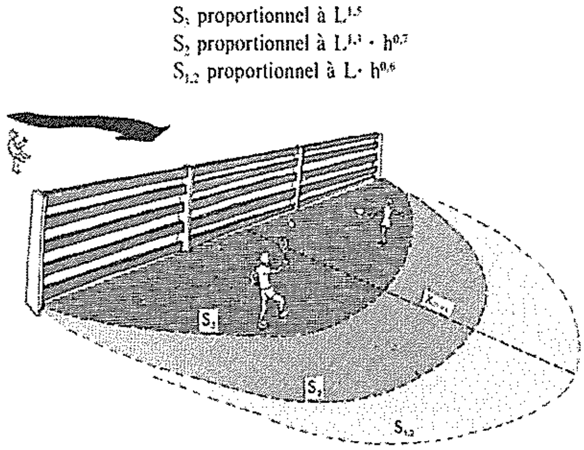
While the shelter f can be infinite, it is provided in three equations where f either = 1.2, 2, or 3

$$S_{1.2} = 16.5h^{0.6} L(-2.7\Phi^2 + 2.5\Phi + 1)K$$

$$S_2 = 1.6h^{0.7} L^{1.3}(-7\Phi^2 + 3.6\Phi + 1)\cos^2 \theta K$$

$$S_3 = 0.6h^{1.5} (-47\Phi^2 + 20\Phi + 1)\cos^2 \theta K$$

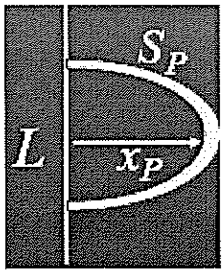
The diagram here shows how each of the $S_{1.2}$, S_2 and S_3 areas relates.
Using this formula, the minimum height, length and porosity of a wind break can be calculated easily and efficiently.



The final formula required for this allows the downwind length of the shelter to be worked out.
This is given as;

$$X_p \geq (4S_p/L\ II)$$

X_p = Length of downwind shelter
L = Length of shelter
S_p = Area



Section 6.2.2 has further information about the design of porous wind shelters.

3.6 Bernoulli's Equation

Bernoulli's Equation is a simplified formula that is used for looking at the relationship between pressure, velocity and wind flow.
It is given as;

$$p + ½pV^2 + pgh = \text{constant}$$

p = pressure
p = density
V = velocity
h = elevation (height of air)
g = gravitational acceleration

The general assumptions are as follows;

- points 1 and 2 lie on a streamline
- the fluid has a constant density
- the flow is steady
- there is no friction

Bernoulli's equation is very useful for looking at winds flows even though it has these seemingly strict assumptions. This is because it is very simple, and does give a good insight into the relationship of pressure, velocity and elevation.

Basically the equation states that in an ideal fluid – in this case air, where there is no forces being applied to it – no friction, then an increase in velocity occurs simultaneously with a decrease in pressure. (Refer to Section 4.1.1 for one situation where the Bernoulli's equation can be applied.)

4.0 The Effects of Buildings on Wind

All buildings create obstacles to wind flows. This causes a positive pressure on the windward face and negative pressure zones on the sides, which in turn causes an increase in wind velocity where the two zones meet.

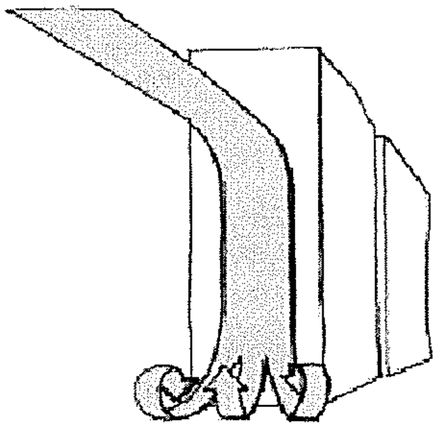
It has already been stated earlier in this design guide that the wind environment created around a building depends on a lot of factors. This section will provide information on how different effects can occur.

4.1 Individual Buildings

Individual buildings are not very common; most of the buildings in the urban environment have more than one surrounding building. The effects that are described below generally occur in isolation, with the effect being different where groups of buildings are concerned.

4.1.1 Downwash

Wind speed increases with height, as explained in the previous chapter. When a tower is exposed to wind speeds, the pressure is higher than that at the base. This different in pressure forces the high pressure at the top down the windward face which dramatically increases pedestrian wind speeds. It naturally follows that the taller the exposed windward is, the higher the pedestrian wind speeds will be.



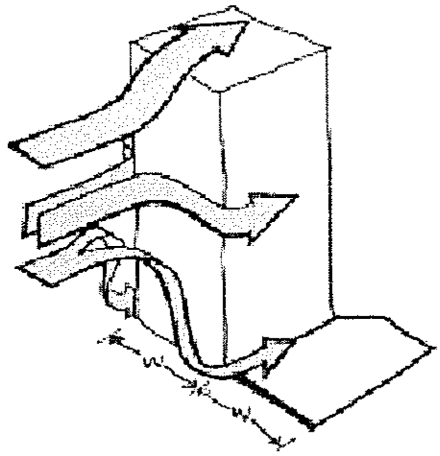
An important thing to remember when designing tall buildings – especially tall, wide rectangular buildings, is that the windward face should be kept as small as possible. The larger the area of the exposed windward face, the more downwash is induced. So tall, wide buildings should be designed with their wide face parallel to the prevailing winds, and their narrower faces exposed – perpendicular to the prevailing wind direction

Generally it is accepted that the following is true for wind and height;

- a 5 storey building will cause a 20% increase in discomfort at pedestrian level
- a 16 storey building will cause a 50% increase
- a 35 storey building will cause a 120% increase

Bernoulli's equation can be applied here as the change in pressure down the windward face of the building induces higher wind speeds at ground level.

4.1.2 The Corner Effect



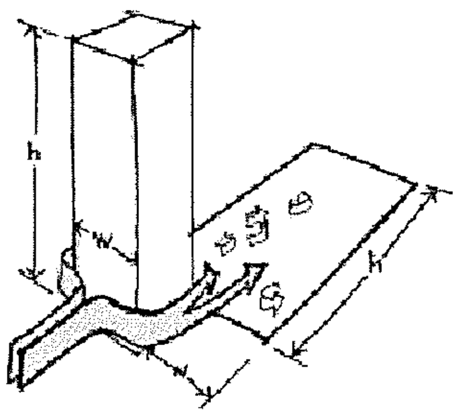
At the windward corners of a building, there can be unexpected increases in wind speeds. This is due to air being forced around the windward corners from high pressures on the windward face to low pressures in sheltered areas at the sides and rear.

The greatest wind speeds occur within an area of equal distance to the width of the building.

Some ways of decreasing this effect are by;

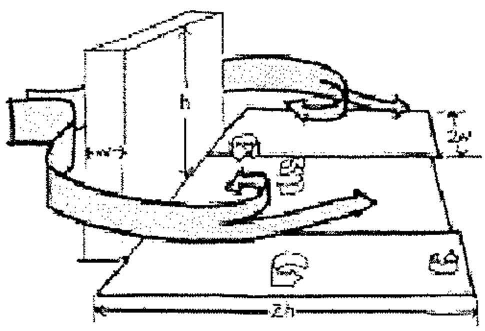
- adding adjacent buildings
- designing the building to have decreasing heights – the pyramid effect discussed in section 5.4, this allows wind to flow over the corner reducing wind speeds caused at the corner
- rounding corners, or adding porous screens or vegetation at corners

4.1.3 The Wake Effect



The wake effect is generally caused by downwash and the corner effect. Increased wind speeds and turbulence that occurs around the corners of buildings lead to increased pedestrian discomfort downwind of buildings. As with the corner effect, the area of greatest discomfort occurs within an area of direct proportion of the height and width of a building.

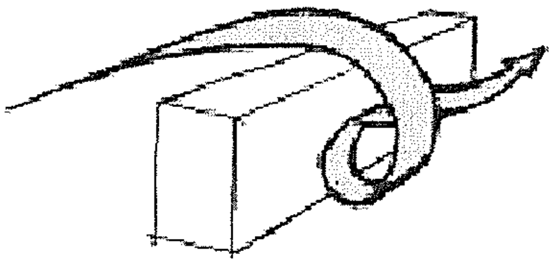
- a 16 storey building would generally cause an discomfort increase of 40%
- a 30 storey building would cause a 120% increase



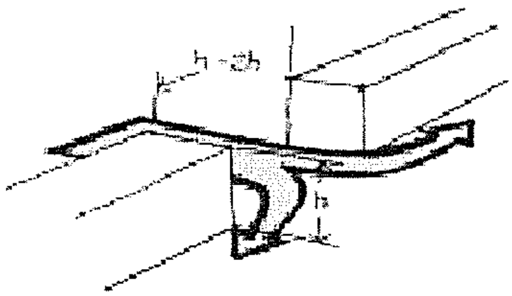
Slab blocks are different however. The length of the discomfort area is generally two times the height, and the width of discomfort area is generally two times the depth of the building either side.

4.1.4 Low Bar – Row Effect

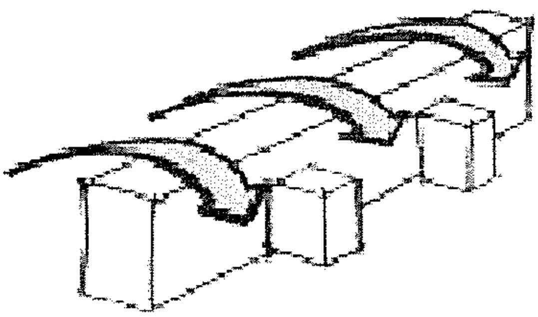
Buildings that have relatively low but wide exposed windward faces cause a wind anomaly called the Row effect. This is where the wind tends to trip or fall over the row of building.



- A narrow building, approximately less than 10 stories high and approximately eight or more times wider than its height causes a 40% increase in discomfort.
- Where there are openings in the row, and the wind direction is perpendicular to the row, there can be up to a 30% increase in discomfort when the width of the opening is only two times the height.



One way to reduce the discomfort created in these situations is to add 'wings' to the building, localising discomfort areas

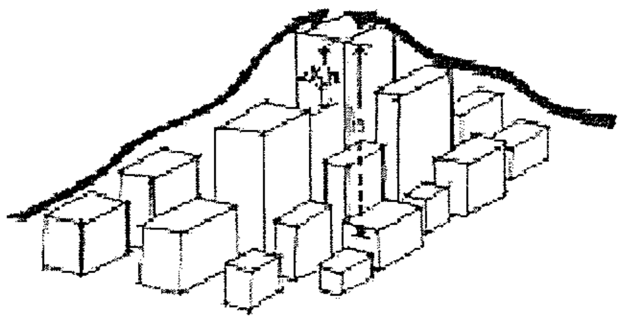


4.2 Groups of Buildings

The effects that occur around individual buildings can not be applied directly to groups of buildings. In these situations, wind movement is quite different. The following sections outline different effects found around groups of buildings.

4.2.1 Cumulative Effect

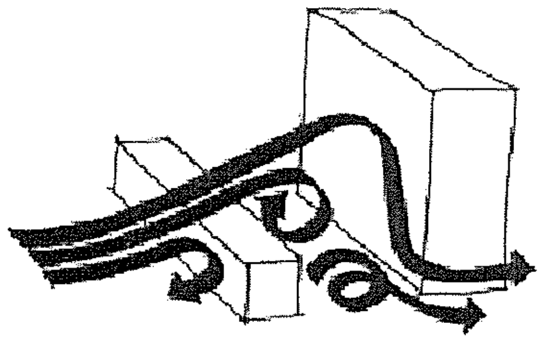
The effects described in section 4.1 are only applicable to individual buildings and how they affect the wind. It must be remembered that in reality, there are usually groups of buildings and in some cases a cumulative wind effect is created. This is when building heights line up so there is a uniform stepping up of building heights so that upward flows add together and increase wind speeds are induced. This also works in the opposite direction – if there is sufficient stepping down then there can be decreases in wind speeds. Generally the cumulative wind effect is only induced when the dominant building is taller than it's surrounding buildings by approximately one third.



4.2.2 Low and High Buildings

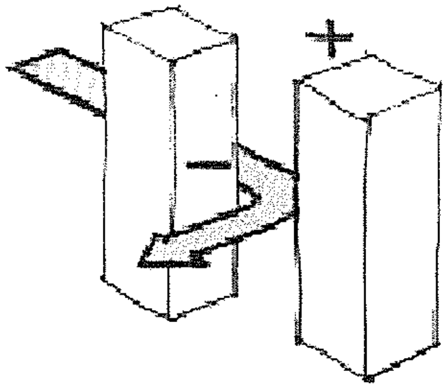
Where there are situations of taller buildings downwind of lower buildings, the combined row and downwash effects can cause extremely high discomfort levels.

- downwash of a 20 storey building windward face can cause a 50% discomfort increase by itself
- however where there is a 5 storey building directly upwind, there would be a 80% increase
- also resulting in a 100% increase in the wake

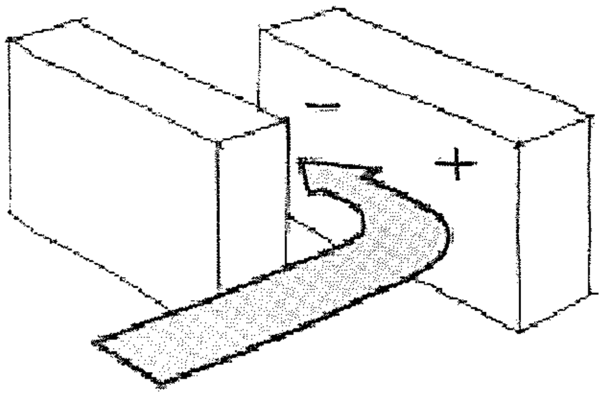


4.2.3 *Staggered Buildings*

Staggered buildings can do one of two things depending on wind direction and size etcetera. They may protect each other or make the wind environment worse. The latter is due to an increased wind pressure at the unsheltered area (+ side in diagrams) and decreased wind pressure at the sheltered areas (- side in the diagrams). This causes wind to rush from high to low pressure areas.

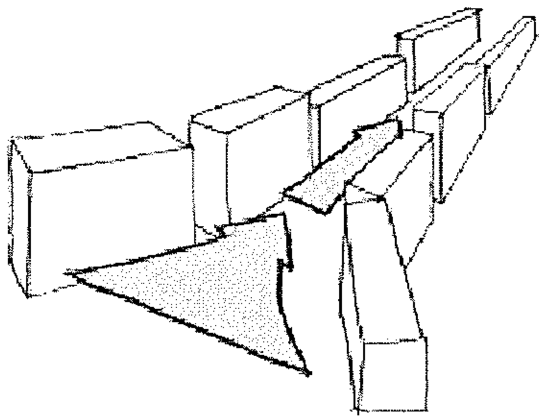


In terms of increases in discomfort levels, the staggering effect is particularly bad. This is because there is no relative increase due to widths, eights and so on. Every situation is different and discomfort levels differ vastly depending on scale and separation of buildings.



4.2.4 *Channelling*

Where there are rows of buildings that run generally parallel to each other they form a corridor. This by itself is not an extremely bad situation, except it is when buildings upwind or along the channel are subject to wind effects and it is transmitted down the corridor that the channel effect is found.

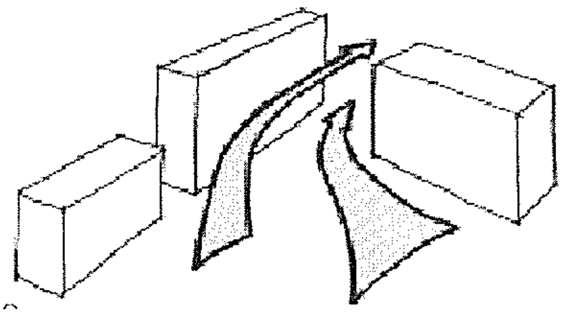


This situation is often worsened when there is;

- little difference between buildings – no gaps
- a general standard height down the corridor
- when the channel is quite narrow compared to building height – roughly less than three times the standard building height.

Often the most effect technique in reducing this effect is to create sharp changes in direction.

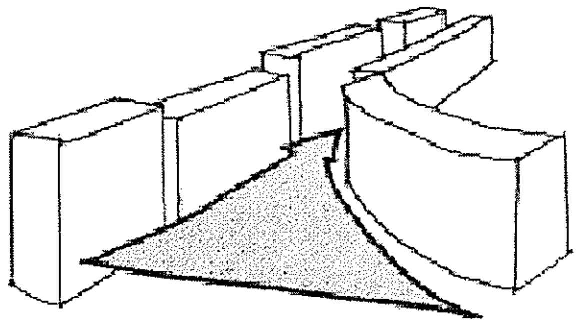
4.2.5 Funnelling



The funnelling effect is caused when there are two or more buildings that meet sharply together, causing a bottleneck. The highest discomfort area is generally at the neck where the funnelling is at its worst as the opening width decreases.

This effect is often exasperated when the two buildings causing the bottleneck are over 5 storeys in height and 100m in length - this maybe a row of buildings of similar height. Also when the width is two or three times the average height discomfort is severely increased. Generally;

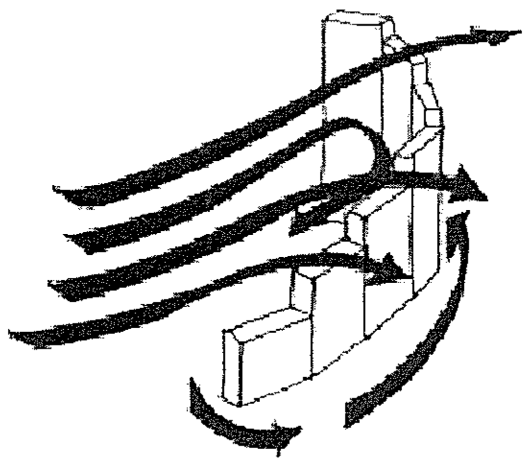
- Buildings that are 8-10 storeys high cause a 30% increase in discomfort
- 18 storey buildings can cause a 60% increase.



Another way that this situation can be worsened further is when what is called the 'Venturi' effect occurs. This is where the corridor following the bottleneck where funnelling occurs diverges together. Here the effect is that the wind speed increases down the corridor after the bottleneck. So extreme is this case that buildings of only 5 storeys high can cause up to a 100% increase in discomfort.

Furthermore, when the buildings creating the funnelling effect are curved, the wind flows around it relatively easily, with little decrease in speed.

4.2.6 Stepping

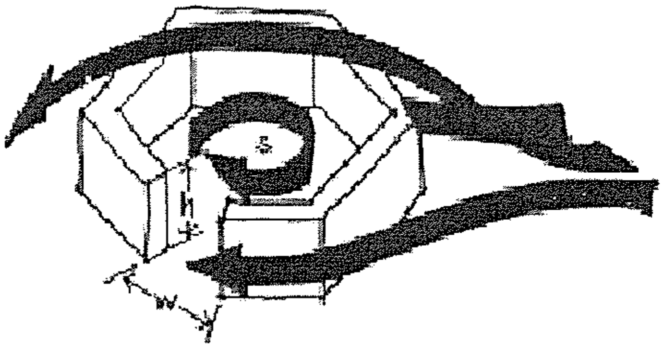


The stepping effect occurs when rows of buildings are stepped in height, and the wind hits their windward faces along this stepping in height.

Each building of different height has different low pressures on the opposite side. As well as the row effect which occurs, added wind flows occur between the varying wind pressures on the downwind side.

4.2.7 Courtyards

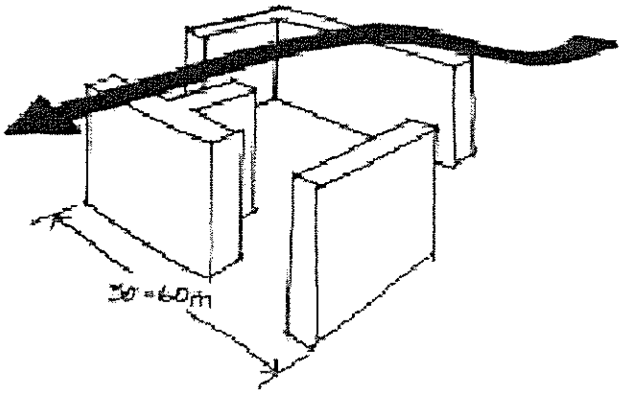
Courtyards create their own effect. It depends on the design of the courtyard and group of buildings that create it whether or not wind will either jump over or blow down into it.



The dependant factors are

- the area of the courtyard (s)
- the average height of the buildings (h)
- the position of the opening and the wind direction
- the width of the opening or total width of openings (w) which should be less than 25% of the total perimeter of the linked buildings

The general rule of thumb for courtyards is that if the average building height is over 4 storeys and the total diameter around 50-60m then there should be a noticed increase in comfort and protection from the wind.



5.0 Building Shape and Wind

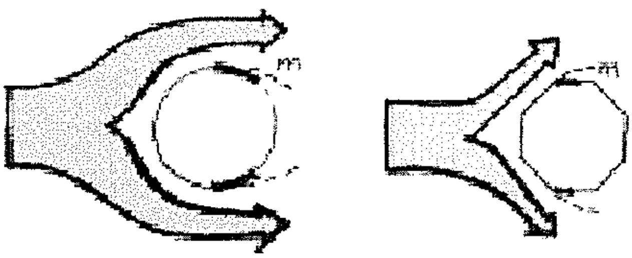
As has been shown in Section 4, all buildings effect the wind environment they are situated in. This section will provide information on particularly common building shapes and key wind effects to be aware of.

5.1 Rectangular Buildings

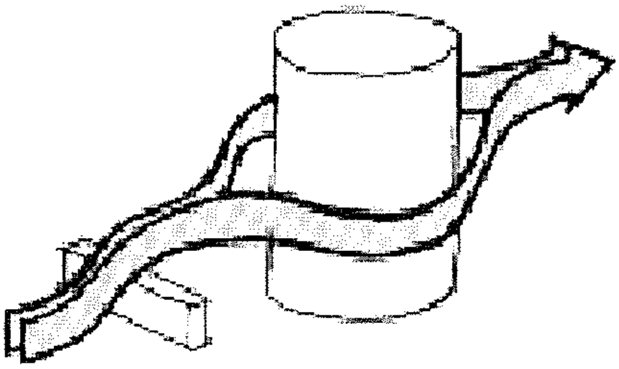
Rectangular buildings are the most common shape of buildings in the urban environment. Rectangular plan forms generally make the most efficient use of the site area. However rectangular buildings are subject to a number of wind effects – perhaps the most out of all commonly used building forms. Although this form is common and the most useful for designers, if possible it is suggested that designers explore other options for the plan form of a building, simply because rectangular buildings can cause so many problems for the surrounding wind environment at pedestrian level.
The common wind effects that designers must be aware of with rectangular buildings are downwash, the corner effect, the wake effect, and the row effect (for long, wide buildings).

5.2 Corner or Multi-Sided Buildings

Buildings that are circular or multi-sided in plan are good building shapes as they encourage the wind to flow laterally around them, and consequentially the effect is that there is little induced downwash.
However the downside is that high wind speeds can still occur at the maximum width at right angles to the wind direction.



One way to counteract this effect is to place these types of buildings downwind to relatively low buildings.

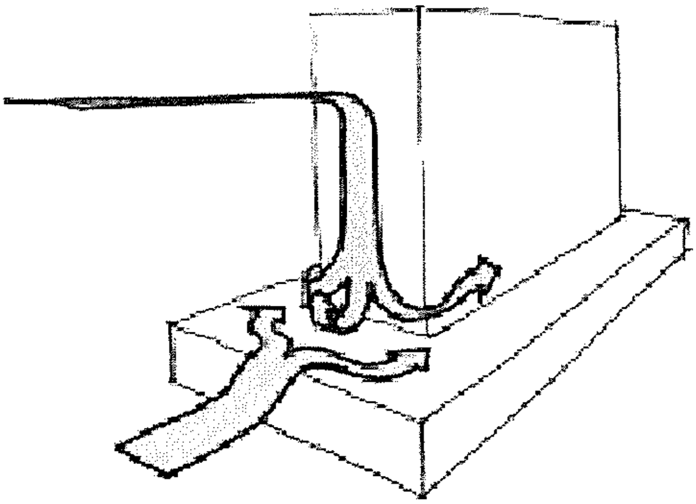


5.3 Tower Podium Buildings

When designed well, tower buildings sitting a top a podium can efficiently reduce pedestrian level wind speeds caused by downwash.

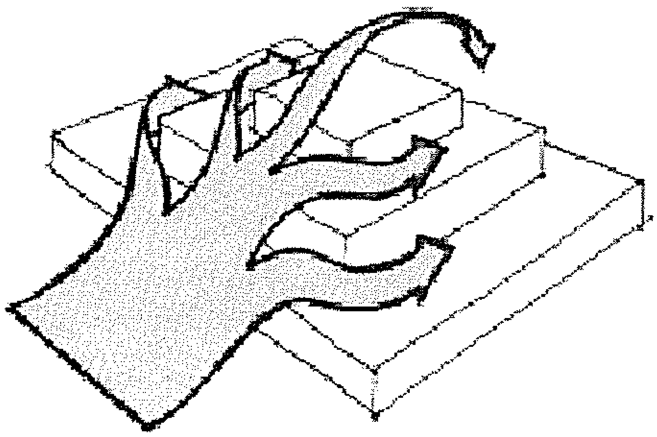
This is because the podium deflects a large amount of downwash away and around the tower before it hits ground level.

Section 6.1.1 provides further information for this type of building design.



5.4 Pyramid Buildings

Pyramid shaped buildings can be very successful in reducing wind speeds at ground level. The rough surface creating by the stepping up of the building helps to decrease the wind speed quite well. As a result, pedestrian levels are quite sheltered.



6.0 Building Design Methods

The following section provides information on how to design particular building details well with respect to the wind environment. Architectural details are generally features of the building form that help can help lessen the wind effects or anomalies that have been described in the previous sections. Often these features are commonly regarded to be simply aesthetic finishing, or remedies that are applied as an after thought to lessen wind effects that may have arisen. However it must be known that there is no alternative to vigilance throughout the design stage to ensure that every effort is made to make a minimal impact on the wind environment.

Also part of this section is advice on some remedial options that can be implemented at the completion of construction if there are major wind issues. Again it must be stressed that these are not good design options and careful attention must be paid at the design stage to ensure that remedial options will not be needed later on.

6.1 Architectural Detailing

6.1.1 Tower and Podium Design

As discussed in Section 5.3, a Tower and Podium design is particularly useful for building form because it deflects any downwash from the tower and dissipates the wind away above pedestrian level.

The key aspects to remember about this type of design are as follows;

- Generally there is no recommended ratio of podium height to tower height for efficient dissipation of downwash. Wind tunnel testing has shown that ratios of 15% to 60% podium height to tower height are effective. The key thing to remember here about effective podium height is that they should be at least 3 storeys high to minimise change in wind speeds and discomfort. Generally a 3 storey building is approximately around 8m high.
- There is also no recommended podium width to tower height ratio. Generally this will depend on site constraints, and the area of the windward face of the tower. However it is generally recommended that providing a podium of around 6m is sufficient to ensure that pedestrian levels are sheltered. A podium width of

around 3m is not sufficient and will only act as a small ledge for wind to move over.

- Wind tunnel testing has also shown that in some cases however depending on the surrounding buildings and the prevailing winds, it is possible to have different podium depths around the tower. For example a wider podium facing the prevailing wind directions and thinner podiums in directions where other buildings around it will help keep downwash and the corner effect from pedestrian level.
- Often depending on the surrounding buildings, it is possible to induce a tower and podium effect where there is a taller building directly adjacent to a smaller building. This smaller building would act as a podium to the taller building, deflecting downwash from its windward face.

6.1.2 Height

Height is a particularly key aspect to designing in urban areas. The general rule of thumb is that the taller the building, the more it will affect the pedestrian level wind environment. Wind tunnel testing has shown that reducing the height of tall buildings by about 25% can reduce wind speeds approximately 2m/s. However every design is different depending on the surrounding environment.

The following information will provide some key things to remember about height when designing in the urban environment.

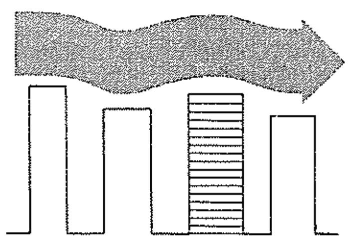
<u>Individual Buildings</u>

Generally it is accepted that the following is true for wind and height;

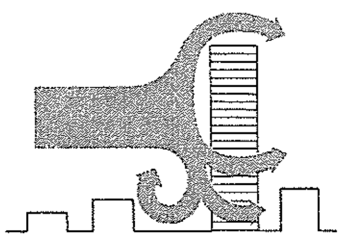
- a 5 storey building will cause a 20% increase in discomfort at pedestrian level
- a 16 storey building will cause a 50% increase
- a 35 storey building will cause a 120% increase

<u>Groups of Buildings</u>

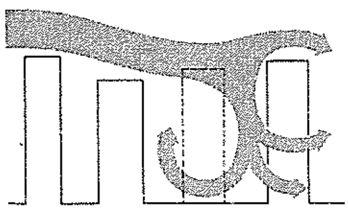
- When a building is similar in height to the surrounding buildings, it will be protected from large wind loads, and there will be little downwash. Clusters of buildings of similar height provide relatively sheltered areas within the cluster with little discomfort increase.



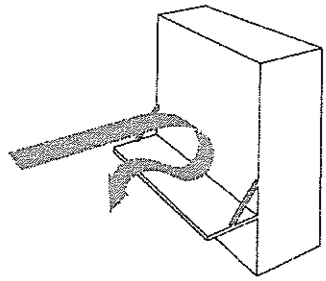
- When a building is taller than the surrounding buildings, large downwash wind effects occur as well as the low and high building effect. If a third of the taller building is higher than the upwind building heights, then high wind speeds at ground level will be induced.



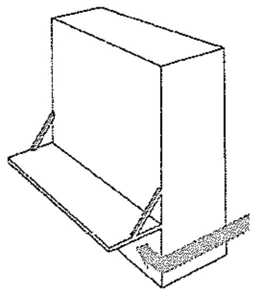
- When a building is much smaller than the surrounding buildings or there is an open space, large downwash effects occur at the next downwind tall building, with the degree of discomfort relative to the open area of space immediately in front.



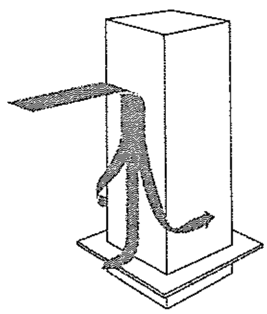
6.1.3 *Canopy and Upstand Design*



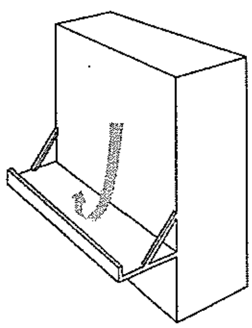
A canopy is a very useful wind design device that helps to reduce the effects of downwash at pedestrian level. A canopy is a minor extension covering doorways and windows. It helps by deflecting the wind vortex created by downwash at the windward face of a building above pedestrian level. However downwash is the only wind effect that is dealt with when using canopies so effects such as the corner effect will still occur. Key issues to remember are;



- Canopies are only useful when facing the wind direction straight on, not when they are parallel to the wind direction as wind can still get to ground level, causing serious discomfort.
- Canopies if possible should be continuous as large gaps induce additional wind currents – similar to openings in rows of buildings where the row effect occurs
- Freestanding canopies do little to stop wind – only rain!

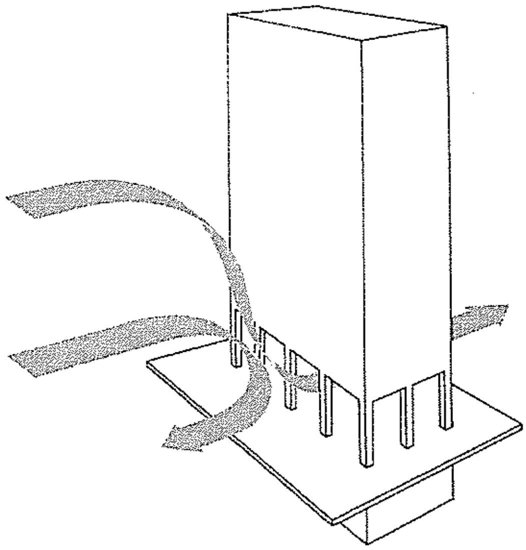


- While canopies are useful in keeping wind away from pedestrian level, unless they are extensive they will do little to relocate the wind. Wind tunnel testing has shown that a 2m wide canopy will have little effect; however 4m or 6m canopies are much more useful.



- The use of upstands in conjunction with canopies are particularly good design. Wind tunnel testing has shown these to have considerable effect on reducing wind disturbances and discomfort, especially when used in conjunction with breezeways as described below.

6.1.4 *Breeze-way Design*



Breezeways are relatively new form of architectural design that deal with the effects of wind. The basic principle of a breezeway is that it is essentially an open passageway through the building that wind can travel through so that it is deflected horizontally before reaching pedestrian level.

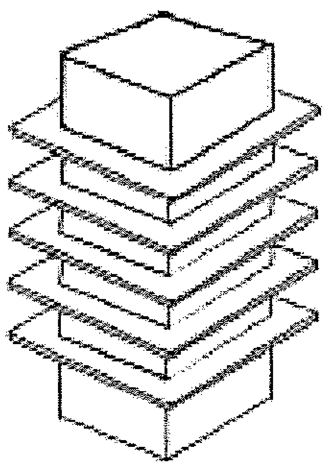
Breezeways can come in a wide range of forms, including;

- entire levels cut out as depicted
- car parking levels with porous surrounds
- or slots through buildings (which can also have the possibility of providing more natural light depending on design)
- in conjunctions with other wind reduction devices such as canopies, upstands, projections, balconies and so on

Breezeways are usually situated on lower storeys (level 2 up) and more often than not they are used as car parking levels. Wind tunnel testing of breezeways has shown that having porosity levels of 50% can provide up to a 10% decrease in wind speeds and 100% porosity can provide 5 – 8% reduction in wind speeds. When teamed with a canopy the effects can be even greater. However where canopies have been placed above the breezeways, the effect has been lost entirely as wind is deflected down to ground level once it has passed through the breezeway.

A breezeway must be open at both sides of the building or else the wind can not flow and its effect is lost.

6.1.5 *Balconies and Projections*



Balconies and projections in the building façade help to disrupt the wind flow down the windward face of a building by creating barriers to the normally smooth flow. The general idea is to break up the façade – increasing the surface roughness which will reduce the intensity of the wind flow down the building.

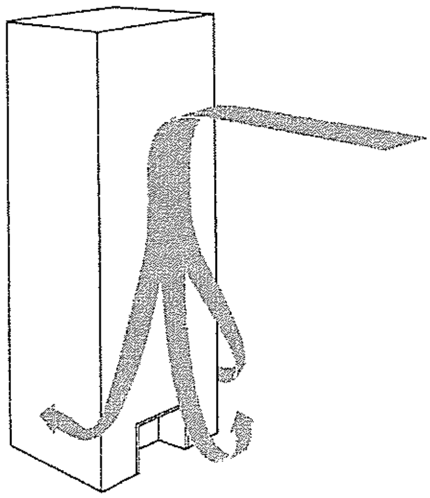
Projections can be horizontal – balconies or vertical – fins. Wind tunnel testing has shown that by including projections of balconies and manipulating the surface roughness can induce reductions in wind speeds of up to 40%. However these are with continuous projections as shown in the figure above. Where balconies are included in the building design it is generally accepted that these are more efficient when larger – at least 3m wide if they are not formed in continuous bands around the building as in the figure to the right.

The Atrium Apartments on The Terrace in Wellington to the right have smaller balconies, which would not provide a substantial disruption in wind flow.

6.1.6 Set-Backs

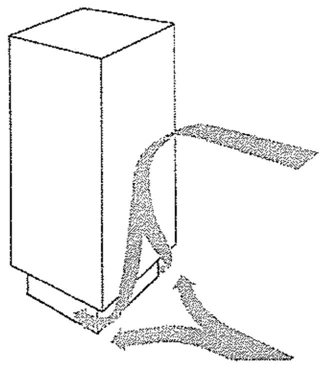
Set backs are one other way of reducing the discomfort levels caused by high wind speeds and downwash. They are efficient because they create a safe zone for pedestrians without any added cost to construction – as with balconies and projections.

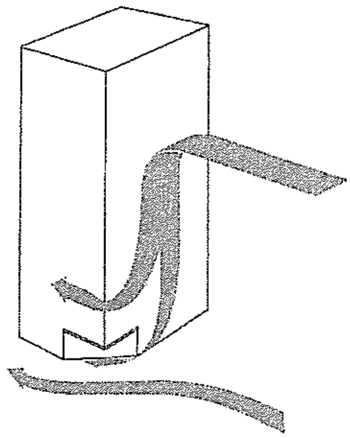
However it is hard to gauge the effectiveness of setbacks, it is very dependant on the wind environment, depth and height.



Setbacks are often used in conjunction with balconies – as seen below right at the 'QBA' apartments on Webb and Cuba Streets in Wellington. Here the surface roughness is broken up with balconies and setbacks, which break up wind flow, and provides pedestrians with safe walking areas at ground level.

Where setbacks are created that run parallel to the prevailing wind however, the effect is lost as it effectively becomes a wind channel at ground level. It is generally recommended that set backs are a minimum depth of 3m or there will be little effect on the wind.

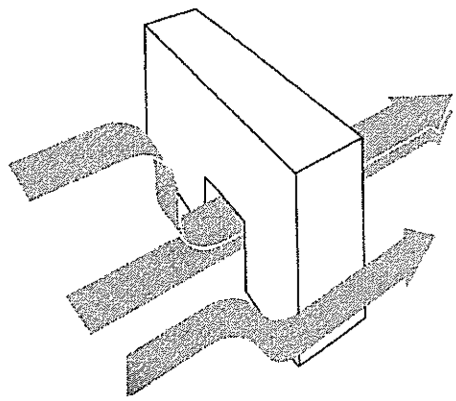




Also where corners are recessed this does little except aggravate the corner effect. It is not recommended that recessed corner entrances are used, except if great care is taken in their design.

6.1.7 Passageways, Corridors and Foyers

Entrances into buildings are a very important aspect in the urban environment. They are transition spaces and need to be designed with care so that they are safe and comfortable for pedestrians.

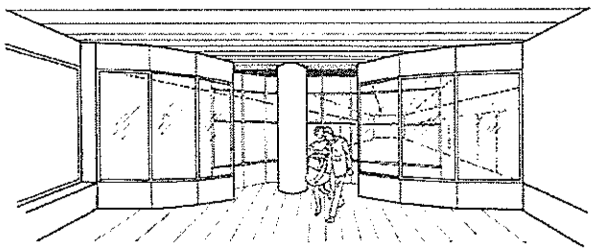


Where passageways are designed only as walkways through buildings and are exposed to the prevailing wind directions, then they are particularly bad design. High pressure wind flows through causing extremely high levels of discomfort. The level if discomfort is directly related to the height of the building, more discomfort due to lower pressures on the lee wind.

- 5 storeys add little added discomfort
- 7 storeys however increase discomfort by 20%
- 16 storeys increase discomfort by 50% in passageways

The area of opening projects the zone of discomfort to the lee side as air is released like a jet stream and there are more directional wind flows at the passageway exit.

Often these spaces are enclosed to become foyers with screens and/or doors at either end. However the wind makes doors bang and hard to open so the entrances and exits of these spaces can become quite unsafe.
The key here is that these spaces must not face into the prevailing wind.

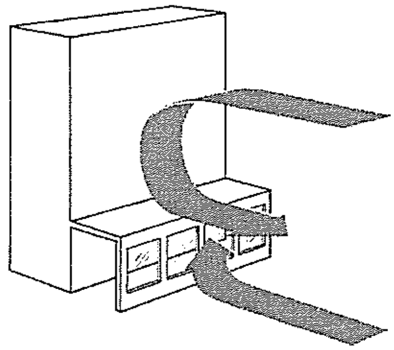


6.2 Remedial Design Options

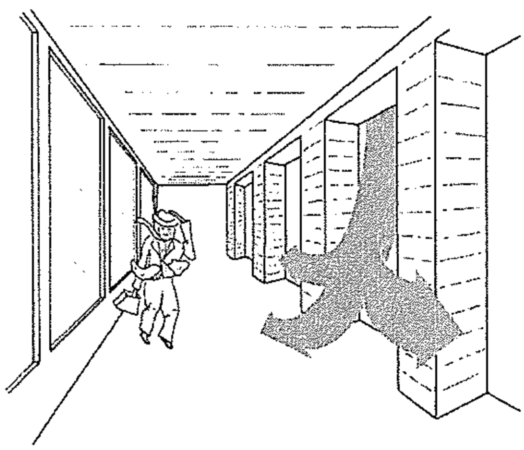
The following is intended to provide information on how to remedy situations where there are extremely poor, uncomfortable and unsafe pedestrian areas around existing buildings. However it can not be stressed enough that with attentive design, these remedial design options should not be necessary and are not substitutes for good design.

6.2.1 Arcades and Colonnades

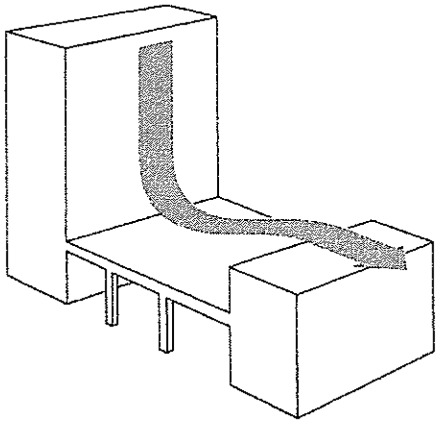
Arcades and Colonnades are roofed over pedestrian walkways. They can either be completely closed in with openings at the ends, or with a roof and columns. Unless designed well they are not recommended for use as a major public access way or for window shopping areas.



The wind issues that occur in these spaces are that there are openings created between high windward pressures and low ground pressures. High wind speeds are induced which can create high discomfort levels down the length of the arcade or colonnade. While enclosed arcades can prevent wind from coming in, the ends and corners can induce the corner effect.
Again like canopies and passageways, arcades and colonnades are only useful when facing the prevailing wind direction, not parallel.



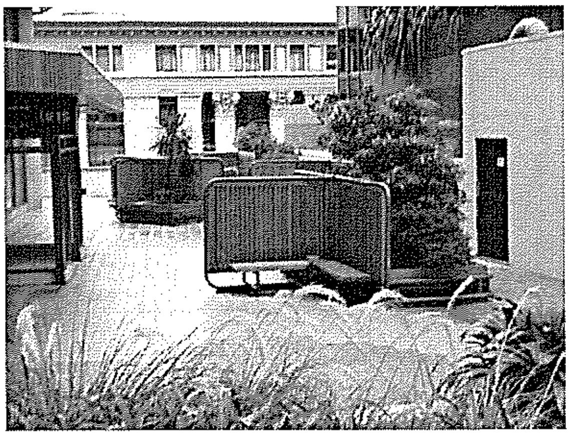
When there are low and high buildings next to each other, due to the low and high effect the space in between has high discomfort effects, it is possible to roof over between the buildings to increase discomfort levels.
Here the wind will flow over the created arcade – provided the openings are not parallel to the wind flows. Again the corner effect maybe induced at the openings in this situation.



6.2.2 *Fences, Screens and Shelters*

Fences, screens and shelters can be a very effective way to remedy a particularly bad wind environment. They can be used in a variety of ways and have many different forms.

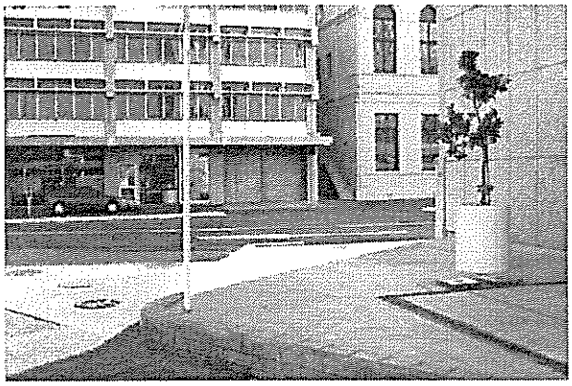
The first is to provide a temporary shelter from the wind (and rain). As shown in the pictures these can be freestanding shelters, depending on the wind direction pedestrians can be sheltered while waiting at intersections. Often these are not designed correctly and are really little more than rain shelters so careful design is often required of these types of shelters.



Another way to provide temporary shelter is to provide quite large shelter around seating. Again there will always be shelter depending on the direction of wind flow.

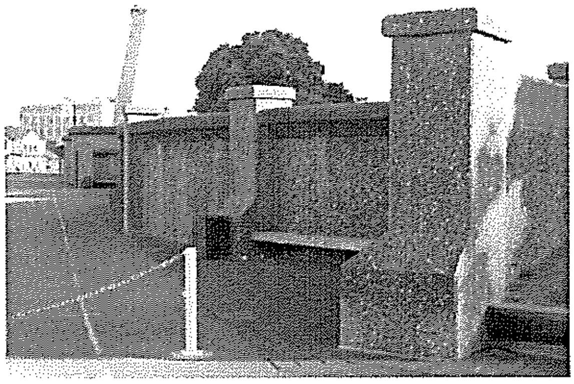
These are example of localised shelters; the following provide a more general form of shelter.

The second use of fences, screens and shelters are to direct people away from an area where particularly bad winds are induced – often around corners.
These maybe in the form of low walls which move the path away from a corner stopping pedestrians walking in the windy area.



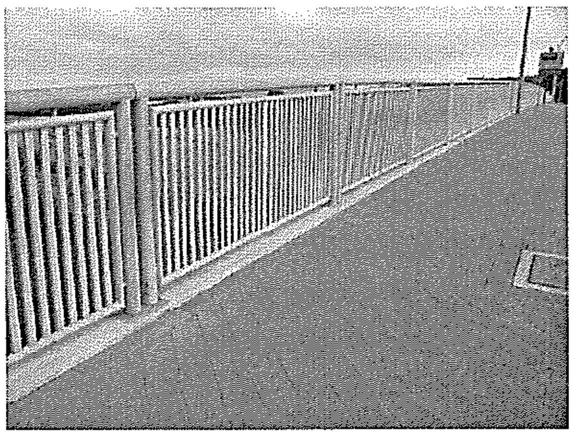
Or as shown around Wellington's Museum Hotel a quite substantial wall is combined with vegetation which shelters pedestrians and restricts them walking in the windy area.

Similarly there are solid wind breaks or fences. These provide good windbreaks at pedestrian level, but do not provide view points so are of little use.



The other option how ever is to use porous wind breaks, as described in Section 3.5.

This particular fence has a porosity of around 50%. (50% of the fence has holes in it that wind can pass through.) 50% porosity is about the maximum porosity a fence should if it is to be an effective windbreak device.
The key to porosity is that provided it is adequately 'solid' (0 – 50%), then its height becomes extremely important. As shown in Section 3.5, a fence two times the height will shelter an area two times as big.

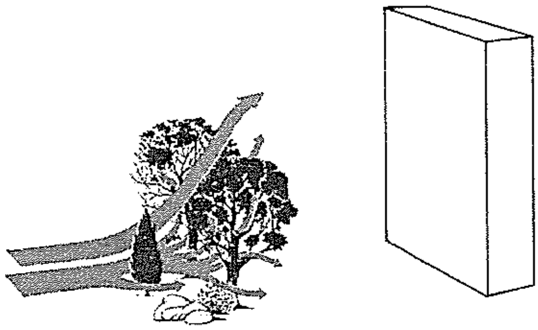


The benefits of a porous windbreak are

- less materials – same amount of materials = larger shelter achieved
- you can see through – viewpoints, great for waterfront locations
- wind loads are smaller

6.2.3 *Vegetation*

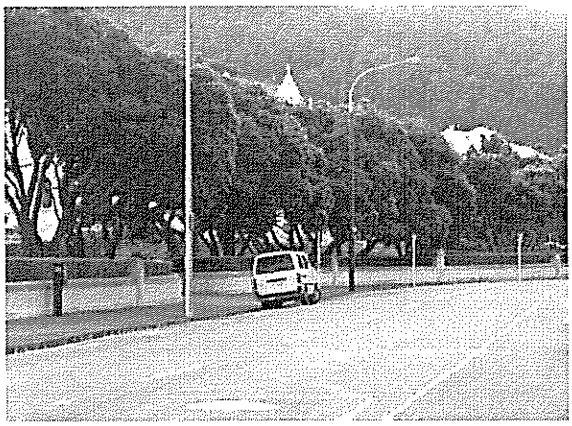
Vegetation acts similarly to porous fences and shelters – the wind is dissipated as it blows through trees, shrubs and hedges. However, unlike man made wind breaks, with vegetation it is difficult to determine how much shelter they will provide.



Singular tall trees that are fairly bare around the base provide little wind shelter as wind can move around the tree at pedestrian level fairly easily. The same goes to unevenly planted groups of trees.

On the other hand, rows of trees that are fairly uniform in height and shape such as the trees depicted below provide a fair amount of shelter as they are large and relatively dense.

Hedges are also very effective at decreasing wind flows around pedestrian level – provided they are allowed to grow to a reasonable height and density.



Like shelters and fences, vegetation provides a good way to dissipate wind and redirect foot traffic away from particularly windy spots.

One important thing to remember is that often it may take time for vegetation to grow to sufficient size to be helpful in dissipating wind.

7.0 Conclusions

Designing a building to have a minimal effect on the wind environment is hard work, and should be undertaken with care and attention. This design guide has provided information to assist designers in making good decisions. It is not intended to provide a complete set of answers on what is good and bad design. Rather it is intended to offer different ideas on what can be useful, what to watch out for and ways to design particular features well.

Building aerodynamics is an intricate topic, and Wellington experiences very complex wind environments. There is no right or wrong answer when designing for the wind. The Wellington City Council requires only that proposed buildings do not make the current situation any worse and this is represented as performance standards in the District Plan. Wind tunnel testing is always part of good design and should be included from an early stage. Having to solve wind problems after construction is annoying for everyone and often remedial designs have little effect or ruin an overall design. There is no substitute for good design and wind tunnel testing should always be a part of that.

The following are some of the key aspects of wind design that have been discussed in full in previous sections.

Key aspects of wind design;

- tall rectangular buildings cause the most wind problems due to height and exposed surface areas of windward faces
- circular or multi-sided buildings promote good wind flows around buildings and induce little downwash, even rounding sharp edges of rectangular buildings will help wind flow better laterally
- keep height similar to that of the building surrounding them so that there is little exposed windward face
- position and align so that windward faces have smaller exposed faces – keep facades with large surface areas away from prevailing winds
- use projections and set backs to break up the flow of the downward wind, such as canopies, balconies, set backs and so on
- when used in conjunction with canopies and upstands, breezeways are efficient options for relocating wind away from pedestrian level and when designed well can become a very attractive building feature
- designing buildings with low level projections around it's base will help to deflect winds away from pedestrian level and dissipate it, this can be through the use of podiums or even pyramid shaped buildings
- keep entrances, walkways and access ways away form windy sides of the buildings and corners, locate them in appropriate areas so that they are not hard to access or unsafe to open

- if wind problems still exist, remedial options such as fences, screens, shelters and vegetation can provide some assistance through dissipating wind or redirecting and restricting pedestrian paths through safer more comfortable areas

8.0 Further Reading and References

8.1 Further Reading

For further reading into the subject of Building Aerodynamics and design the following sources are particularly useful;

Aynsley R.M, Melbourne W, & Vickery B.J, 1977. *Architectural Aerodynamics*, Applied Science Publishers, Essex, England.

Blocken B & Carmeliet J, 2004. *Pedestrian Wind Environment around Buildings: Literature Review and Practical Examples*, Journal of Thermal Envelope and Building Science, Volume 28, Number 2, pg 107 – 159.

Gandemer, J, 'Wind Environment Around Buildings: Aerodynamic Concepts', Proceedings of Fourth International Conference on Wind Effects on Buildings and Structure, Heathrow 1975. Page 423-432

Scholes, J, 'Building Aerodynamics and Pedestrian Comfort', Victoria University of Wellington, 1987

Wellington City Council District Plan, DATE, *Plans and Policies - The District Plan - Introduction*, viewed 28th April 2007, http://www.wellington.govt.nz/plans/district/districtplan.html

8.2 References

Architecturenz.net, (no date). *Street Corner Canopies*, viewed 28th April 2007, http://www.architecturenz.net/galleryItem.aspx?g=e168c122-f90f-44f8-b860-e6edff43b717&i=2&k=&l=&pt=&pr=0&pg=0

Aynsley R.M, Melbourne W, & Vickery B.J, 1977. *Architectural Aerodynamics*, Applied Science Publishers, Essex, England.

Blocken B & Carmeliet J, 2004. *Pedestrian Wind Environment around Buildings: Literature Review and Practical Examples*, Journal of Thermal Envelope and Building Science, Volume 28, Number 2, pg 107 – 159.

Building Research Establishment, England, 1994. *Wind around Tall Buildings*, BRE Digest 390, Building Research Establishment, Watford, England

Carpenter P, 1988. *The Wind Environment in Wellington City – Full Scale Measurements and Comparisons with Wind Tunnel Tests*, Central Laboratories Report 9-88/1, Central Laboratories, Lower Hutt, Wellington New Zealand.

Carpenter P, Jamieson N & Locke N, 2002. *Wind in the City Streets*, Central Laboratories, Opus International Consultants Ltd, Lower Hutt, Wellington New Zealand.

Coonley D.R, 1974. *Design with Wind*, Total Environmental Action, Harrisville, United States of America. Originally submitted for partial fulfilment of a March, Massachusetts Institute of Technology, May 1974.

Donn, M, 2004. *Wind in the City – Building Aerodynamics*, BBSC 231 Lecture Notes on Building Aerodynamics, School of Architecture, Victoria University of Wellington, Wellington, New Zealand.

Donn, M, 2004. *Wind Shelter – Porosity, Height, Length and Comfort*, BBSC 231 Lecture Notes on Wind Shelter, School of Architecture, Victoria University of Wellington, Wellington, New Zealand.

Efluids Bicycle Aerodynamics, (no date), *Bernoulli's Equation*, viewed 28th April 2007 http://www.efluids.com/efluids/bicycle/bicycle_pages/Bernoulli.jsp

Gandemer, J, 'Wind Environment around Buildings: Aerodynamic Concepts', Proceedings of Fourth International Conference on Wind Effects on Buildings and Structure, Heathrow 1975. Page 423-432

ING Properties, 31st January 2007. *Properties – Commercial*, viewed 28th April 2007, http://www.ingproperty.co.nz/WEB/webp.nsf/content/Properties

Scholes, J, 'Building Aerodynamics and Pedestrian Comfort', Victoria University of Wellington, 1987

Wellington City Council, New Zealand, 1984, *Design Guide for the Wellington City Centre*, Town Planning Department, Wellington City Council, Wellington, New Zealand

Wellington City Council District Plan, DATE, *Plans and Policies - The District Plan - Introduction*, viewed 28th April 2007, http://www.wellington.govt.nz/plans/district/districtplan.html